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Potential Sampling Strategy for Solid Particle Input Accountancy Tank (IAT)

Tae-Sic Yoo, Brian Westphal, James King

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Decladding Operation

- **[Davis et.al. 1979] Oxide particle size distribution with shearing clad: need to handle various size particles**

Table 11. Ranges of mass distribution by particle size for irradiated fuels[a]

Particle sieve size (μm)	Weight in sizes less than the indicated value (%) Minimum	Maximum	Particle sieve size (μm)	Weight in sizes less than the indicated value (%) Minimum	Maximum
1	0.000038	0.12	140	7.56	36.2
2	0.00045	0.39	160	8.30	39.3
4	0.0042	1.12	180	8.99	42.1
6	0.014	1.96	200	9.65	44.7
8	0.031	2.83	250	11.2	50.2
10	0.056	3.71	300	12.5	54.7
15	0.15	5.88	350	13.7	58.5
20	0.30	7.95	400	14.9	61.7
30	0.71	11.7	450	15.9	64.5
40	1.26	15.1	500	16.9	66.9
50	1.90	18.1	600	18.7	70.9
60	2.61	20.8	700	20.3	74.1
80	4.18	25.6	800	21.7	76.7
100	5.87	29.6	900	23.0	78.9
120	6.77	33.2	1000	24.2	80.7

Decladding Operation

- **[Lassmann et.al. 1994] Pu radial distribution; the closer to the cladding the higher Pu concentration**

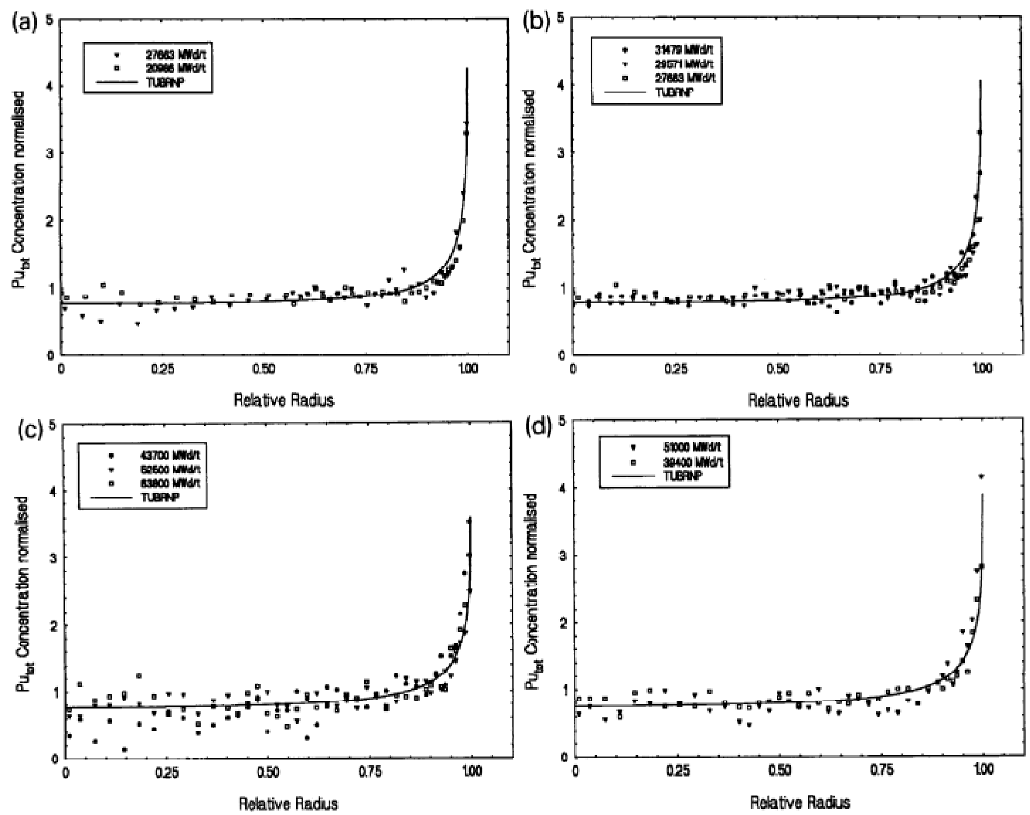

Fig. 1. (a) Comparison of the radial total Pu concentration measured in different STRO fuels (enrichment $^{235}U = 2.9\%$) with that calculated by the TUBRNP model for 25000 MWd/t. (b) Comparison of the radial total Pu concentration measured in different STRO fuels (enrichment $^{235}U = 2.9\%$) with that calculated by the TUBRNP model for 29000 MWd/t. (c) Comparison of the radial total Pu concentration measured in different EPRI fuels (enrichment $^{235}U = 5.75\%$) with that calculated by the TUBRNP model for 55000 MWd/t. (d) Comparison of the radial total Pu concentration measured in different EPRI fuels (enrichment $^{235}U = 8.25\%$) with that calculated by the TUBRNP model for 45000 MWd/t.

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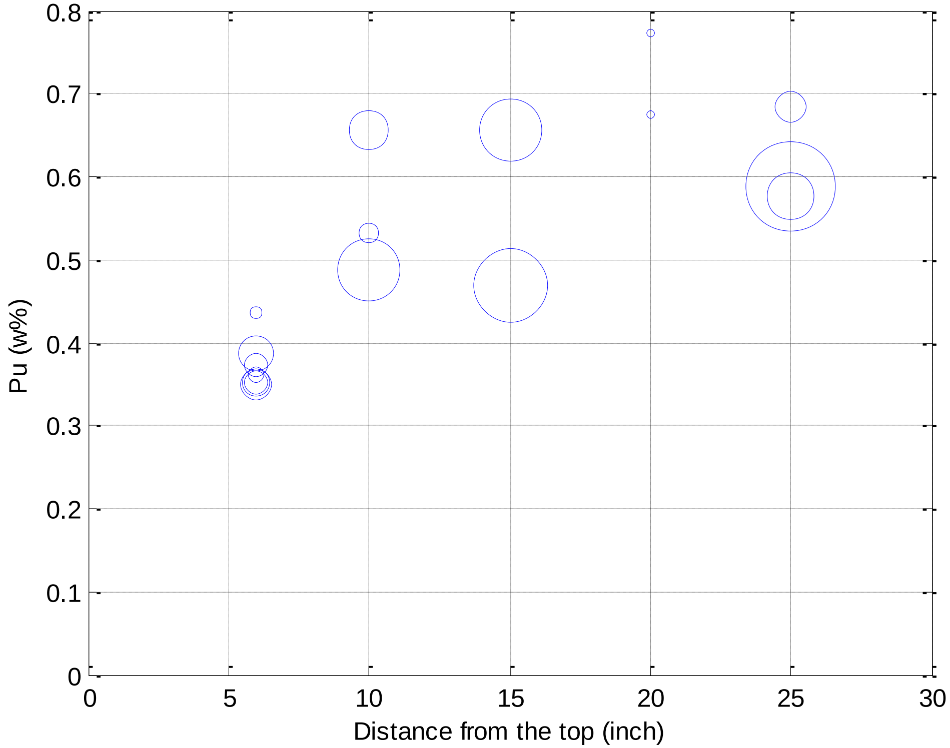
BR-3 Pu Axial Distribution



- **Heterogeneous Pu distribution axially**

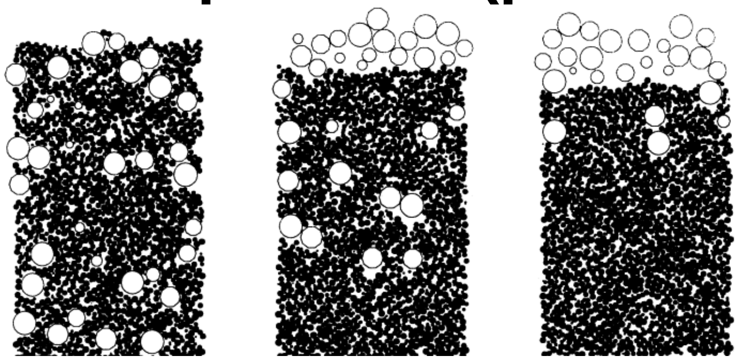
Decladding Process

- An option dissolving the entire oxide fuels to an Input Accountancy Tank (IAT) is not available for pyroprocessing
- Various size particle handling or treatment is "necessary" for a simple mechanical decladding such as shearing
- Heterogeneous Pu radial and axial distributions

- Received a pile of decladed oxide fuel particles of various particle sizes
- Obtain a representative sample to estimate the composition of the particle pile

Process Requirements

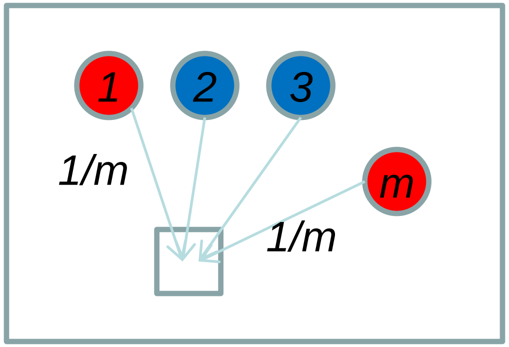
- Representative sample does not have to be homogeneous
- Homogeneity is hard to achieve/validate, in particular, for solid particles (particle segregation)



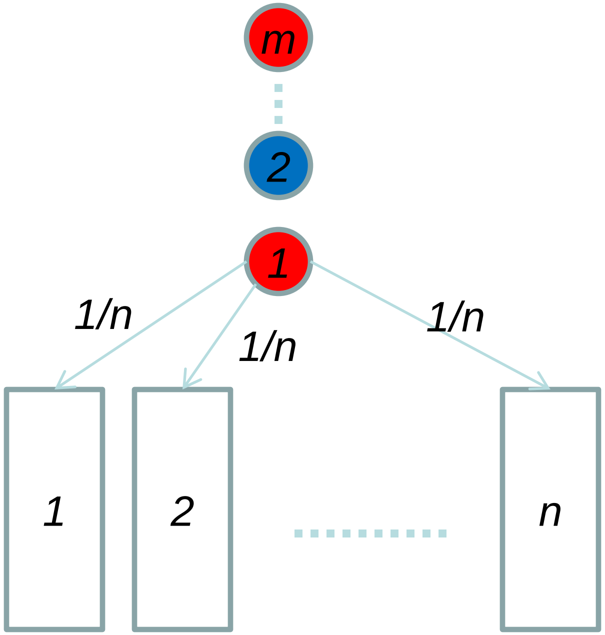
- For pyroprocessing, the necessary property of the sample is “representativeness (composition of bulk)”
- Alternative way to prepare a representative sample and the batches without homogenization?

Ways to Randomize

- **Homogenization: Given a spatial coordinate, assure equal chance to every particle to be at the coordinate; mix, shake, etc.**

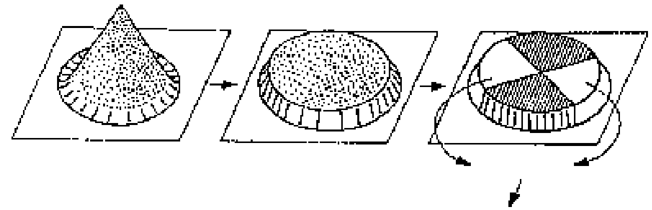


- **Equally-likely partition: Given a particle, assure equal chance of being at each jar**

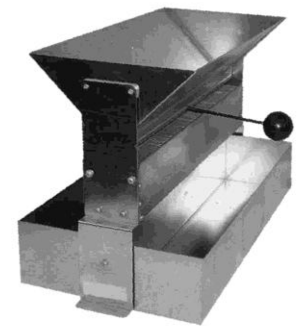


Representative Sample

- Coning and quartering



- Chute splitter



- Rotary riffler

Representative Sample

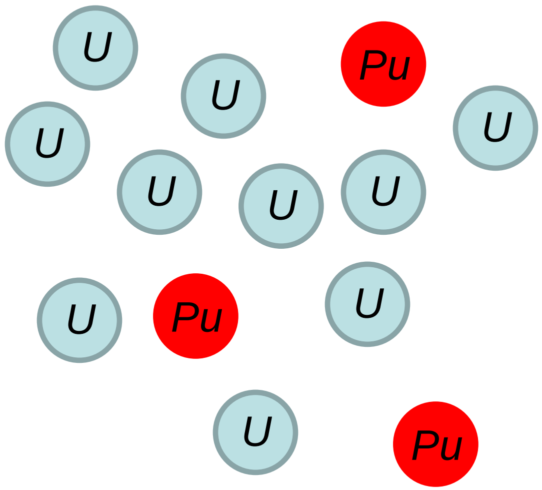
- **Performance of sampling devices [Allen and Khan 1970]**
  - Sand Mix: 60 % coarse (500-420 micron) 40% fine (250-150 micron)
  - Sugar-Sand : 60 % sand (500-420 micron) 40 % sugar (500-420 micron)

Sampling Method	Sand Relative Std (%)	Sugar-Sand Relative Std (%)
Cone and quarter	6.81	5.76
Scoop	5.14	6.31
Table splitter	2.09	2.11
Chute splitter	1.01	1.10
Rotary riffler	0.125	0.27
Random variation	0.076	0.093

Sampling Particles

- **How much is enough to get representative sample?**
- **Arguments based on probability theory**
  - Worst case analysis
  - Conservative analysis based on fuel data

Binomial Distribution



- A pile of balls where the numbers of U and Pu balls are p and q, respectively
- Draw n balls from the pile and count Pu balls
- When p and q are large enough, approximated with drawing balls with replacement
- Binomial distribution; the largest variance distribution among distributions with mean, nq/(p+q), and the bounded outcome space, [0 n]

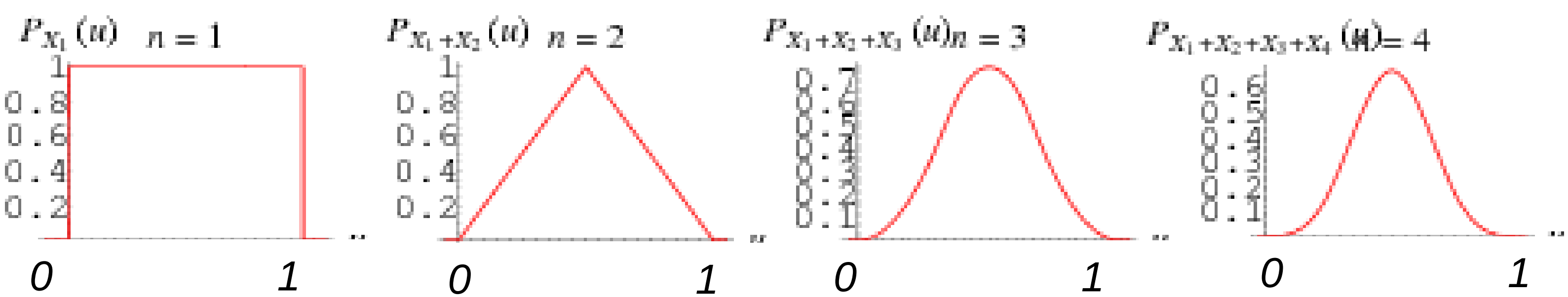
$$P(\#Pu = k) = P(B_1 + B_2 + \ldots + B_n = k) = \binom{n}{k}\left(\frac{p}{p+q}\right)^k \left(\frac{q}{p+q}\right)^{n-k}$$

Central Limit Theorem

- Loosely speaking, any sample average converges to normal distribution

$$S_n = \frac{X_1 + \cdots + X_n}{n}$$

- Shape gets narrower and narrower (lower variance)
- How large n should it be to have enough confidence



Background Theory

- **Independent identical random variable {X_i : i = 1, 2, …}**
- **With CLT,** $S_n = \frac{X_1 + \cdots + X_n}{n}$ **converges to a normal distribution**
- **Assume that outcome of X_i defined over [0 β]**
- **With binomial distribution variance upperbound, the variance of S_n, Var(S_n), satisfies the below**

$$Var(S_n) = \sigma^2 = \frac{Var(X_1) + \cdots + Var(X_n)}{n^2} = \frac{Var(X_1)}{n} \leq \frac{\alpha\beta - \alpha^2}{n}$$

Background Theory

- **x-σ confidence level requirement on y% relative error on estimated mean value gives**

$$n > \frac{10000x^2(\beta - \alpha)}{y^2\alpha}$$

- **While the exact value of α := E(X_i) is unknown, assume that a lower bound $\alpha_l \leq \alpha$ is known**

- **Confidence requirement is guaranteed for all α such that $\alpha_l \leq \alpha$ when**

$$\boxed{n > \frac{10000x^2(\beta - \alpha_l)}{y^2\alpha_l}}$$

Sufficient Sample Mass

- α_l : average Pu concentration lower bound
- β: individual particle Pu concentration upperbound
- Cube particle with density 10g/cc
- Sampling error less than y = 1% with 99.7% (x = 3) confidence

α_l	β	$1mm$	100 $micron$	10 $micron$
0.1%	5%	44.1 kg	44.1 g	44.1 mg
0.1%	10%	89.1 kg	89.1 g	89.1 mg
0.1%	20%	179.1 kg	179.1 g	179.1 mg
0.5%	5%	8.1 kg	8.1 g	8.1 mg
0.5%	10%	17.1 kg	17.1 g	17.1 mg
0.5%	20%	35.1 kg	35.1 g	35.1 mg

Sieving Rotary Riffler

- 2.5L capacity (up to 6 pins: ~12 kgHM)
- 20x20x20” (51x51x51cm)
- 1/8 split
- Simple design and operation
- Suitable for remote handling
- Easy insertion of a sampler to decrease sample size

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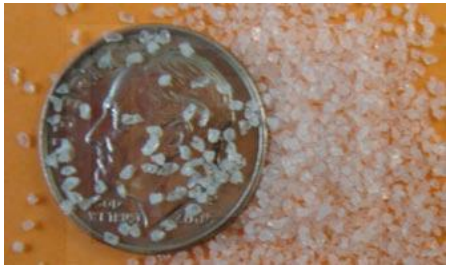
Equipment Validation

16 mesh ~ 1mm



30 mesh ~0.5mm

- **Various size free flowing alumina (16 and 30 mesh)**
- **May not incur an interaction of very fine particles and conglomerations, which can be detrimental to splitter performance**

500mesh ~12 micron

1000 mesh ~5 micron

Rotary Riffler Performance

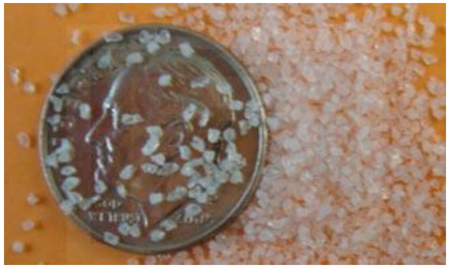
- 16 mesh alumina grit (1~1.4 mm mix)
- 30 mesh alumina grit (0.5~1 mm mix)
- Alumina grit density: 3.8 g/cc
- Alumina grit bulk density (with void): 1.7g/cc
- Estimated shape factor: 1.7/3.8 ~ 0.44

- 8 bin split
- Rotation speed: 45 rpm

Mixture Experiment

- **Mixture of 16 and 30 mesh alumina**

16 mesh



30 mesh

- **Pre-sieved multiple times with 850 micron sieve to filter intermediate sized particles**
- **100 particles were sampled to give average particle mass**
  - 16 mesh: 5.55 mg
  - 30 mesh: 0.62 mg
- **Mixtures were hand mixed with shaking before being placed into the vibratory hopper**

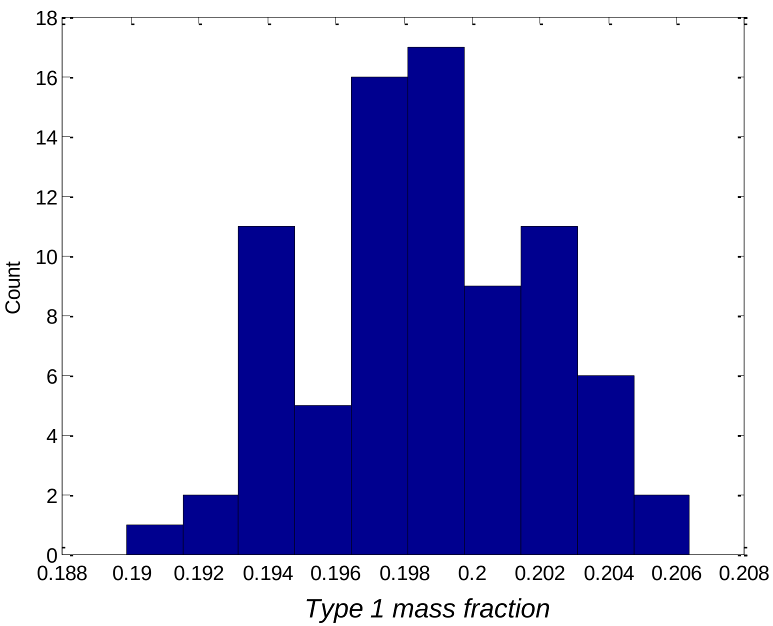
Mixture Experiment
8 bin split (20g x8); 45 rpm; ~16g/min

b_1~ 32 g
Avg. mass 0.62mg

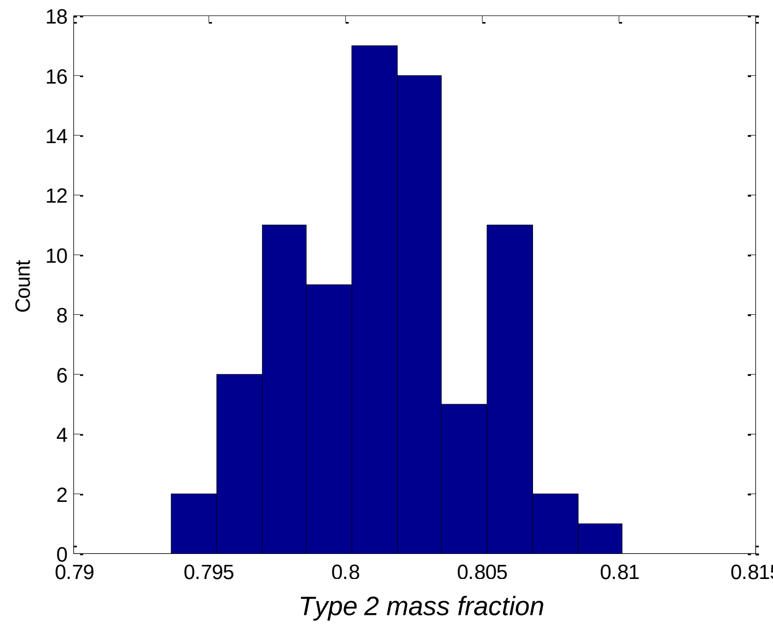
1:4

b_2~ 128 g
Avg. mass 5.55mg

$$Y_1=m_1X_1/(m_1X_1+m_2X_2)$$

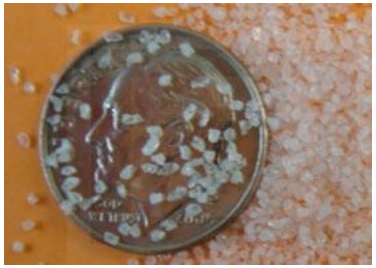


$$Y_2=m_2X_2/(m_1X_1+m_2X_2)$$



Mixture Experiment
8 bin split (20g x8); 45 rpm; ~16g/min

b_1~ 32 g
Avg. mass 0.62mg



1:4

b_2 ~ 128 g
Avg. mass 5.55mg

	Relative Standard Deviation of Samples (%)	
	$m_1X_1/(m_1X_1+m_2X_2)$	$m_2X_2/(m_1X_1+m_2X_2)$
Measured	1.669	0.417
Calculated	1.677	0.419

Remarks

- No need for homogenized input batch as oxides will be dissolved to the salt
- Crushing the fuel and sample with a rotary riffler type divider/sampler
- Confirmed the performance of the rotary riffler with mixed size alumina
- Derived sufficient sample masses are applicable for homogenized particle mix as well